Claims

[c1] 1. A multi-phase ceramic composite material comprising:
-a proton conducting ceramic phase having a protonic conductivity greater than 1.0×10^{-3} S/cm at an operating temperature; and
-an electron conducting ceramic phase with electronic conductivity greater than 1.0×10^{-2} S/cm when measured under reducing conditions with an oxygen partial pressure less than 0.05 atm.

[c2] 2. The material in accordance with Claim 1, wherein the electron conducting ceramic phase is substantially structurally and chemically identical to at least one product of a reaction between the proton conducting phase and at least one expected gas under operating conditions of a membrane fabricated using the material.

[c3] 3. The material in accordance with Claim 1, wherein the electron conducting ceramic phase is structurally and chemically identical to at least one product of a reaction between the proton conducting phase and at least one expected gas under operating conditions of a membrane fabricated using the material.

[c4] 4. The material in accordance with Claim 1, wherein the electron conducting ceramic phase has a form $Ce_{1-x}B_xO_{2-\epsilon}$, wherein B represents one of yttrium and an element belonging to the Lanthanide series in the periodic table, and ϵ is an oxygen deficiency.

[c5] 5. The material in accordance with Claim 2, wherein the electron conducting ceramic phase has a form $Ce_{1-x}B_xO_{2-\epsilon}$, wherein B represents one of yttrium and an element belonging to the Lanthanide series in the periodic table, and ϵ is an oxygen deficiency.

[c6] 6. The material in accordance with Claim 4, wherein $0 \leq x \leq 0.75$.

[c7] 7. The material in accordance with Claim 4, wherein $0 \leq x \leq 0.75$.

[c8] 8. The material in accordance with Claim 1, wherein the proton conducting ceramic phase has a perovskite structure.

[c9] 9. The material in accordance with Claim 8, wherein the electron conducting phase is a ceria.

[c10] 10. The material in accordance with Claim 8, wherein the electron conducting phase is a doped ceria.

[c11] 11. The material in accordance with Claim 8, wherein the perovskite has a form $A_{1-x-\alpha}P_xB_{1-y}Q_yO_{3-\delta}$, wherein A is a bivalent cation selected from the group consisting essentially of barium (Ba), strontium (Sr), calcium (Ca) and magnesium (Mg) and combinations thereof, P is an A-site dopant, which is a cation, B is a tetravalent cation selected from the group consisting essentially of an element in Group IV of the period table, and an element in the lanthanide series of the periodic table, Q is a B-site dopant selected from the group consisting essentially of an element in Group III of the period table, and an element in the lanthanide series of the periodic table, α is a non-stoichiometric A-site deficiency and δ is an oxygen deficiency.

[c12] 12. The material according to claim 11, wherein the A-site dopant is a cation selected from the group consisting essentially of Pr, Sm, Er and an element in the lanthanide series of the periodic table.

[c13] 13. The material in accordance with Claim 11, wherein $0 \le \alpha \le 0.1$.

[c14] 14. The material in accordance with Claim 11, wherein $0 \le x \le 0.5$.

[c15] 15. The material in accordance with Claim 11, wherein

$0 \leq \gamma \leq 0.3$.

[c16] 16. The material in accordance with Claim 1, wherein the proton conducting ceramic phase has a pyrochlore structure of $(A'_{2-\gamma}A''_{\gamma})_2(B_{2-\eta}R_{\eta})O_{7-\lambda}$ wherein A′ is a trivalent cation, A″ is a divalent cation, B is a tetravalent cation and R is a divalent cation

[c17] 17. The material in accordance with Claim 16, wherein A″ and R are identical cations.

[c18] 18. The material in accordance with Claim 16, wherein $0 \leq \gamma \leq 0.3$.

[c19] 19. The material in accordance with Claim 16, wherein $0 \leq \eta \leq 0.3$.

[c20] 20. The material in accordance with Claim 1, where the proton conducting ceramic phase is a complex perovskite.

[c21] 21. The material in accordance with Claim 20, wherein the complex perovskite has a structure of $A_2(B'_{1+\beta}B''_{1-\beta})O_{6-\lambda}$, wherein A is a divalent ion, B′ is one of a trivalent ion and a tetravalent ion, and B″ is a pentavalent ion.

[c22] 22. The material in accordance with Claim 21, wherein $0 \leq \beta \leq 0.3$.

[c23] 23. The material in accordance with Claim 21, wherein $0 \leq \phi \leq 0.2$.

[c24] 24. The material in accordance with Claim 20, wherein the complex perovskite has a structure $A_3(B'_{1+\beta}B''_{2-\phi})O_{9-\lambda}$, wherein A is a divalent ion, B′ is one of a trivalent ion and a tetravalent ion, and B″ is a pentavalent ion.

[c25] 25. The material in accordance with Claim 24, wherein $0 \leq \beta \leq 0.3$.

[c26] 26. The material in accordance with Claim 24, wherein $0 \leq \phi \leq 0.2$.

[c27] 27. The material in accordance with Claim 1, wherein the ceramic phase has one of a low protonic conductivity and a low electronic conductivity.

[c28] 28. The material in accordance with Claim 1, further comprising a secondary ceramic phase added below a percolation limit to improve thermodynamic stability.

[c29] 29. The material in accordance with Claim 1, further comprising a second electronically conducting phase selected from the group consisting of tin oxide (SnO_2), doped SnO_2, tungsten oxide (WO_3), doped WO_3, cobalt oxide (CoO_3), doped CoO_3 and silicon carbide (SiC).